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K'-Band Spectro-imagery of AFGL 2688 and NGC 7027

Pierre Cox[1], Jean-Pierre Maillard[2], P.J. Huggins[3] T. Forveille[4], R. Bachiller[5], S. Guilloteau[4] and A. Omont[2]

[1] *Observatoire de Marseille, France and MPIfR, Bonn, Germany*
[2] *Institut d'Astrophysique, CNRS- Paris, France*
[3] *Physics Department, New-York University, U.S.A.*
[4] *Institut de Radioastronomie Millimétrique, Grenoble, France*
[5] *Centro Astronòmico de Yebes, Spain*

Abstract. We report high spatial and spectral resolution near-infrared mapping results in the K'–Band obtained with BEAR towards the proto-planetary nebula AFGL 2688 and the planetary nebula NGC 7027.

1. Introduction

A large population of planetary nebulae (PNe) are now known to have massive envelopes of molecular gas which have been mainly detected in the emission of H_2 and CO (Huggins et al., 1994). The physical conditions of the neutral gas are closely linked to the processes which determine the evolution of the envelopes. The molecular envelope, which was ejected by the red giant progenitor, is exposed to extremely high ultraviolet radiation fields from the central star (10^2 to 10^6 times the average interstellar field) and is subject to compression and fragmentation, from the effects of ionization fronts and/or fast winds. Theoretical understanding of both the gas dynamics and the unusual photon dominated regions (PDRs) which develop in these is still incomplete (Tielens, 1993). The rapid transition between the Asymptotic Giant Branch (AGB) and the PNe phase (the proto-PNe phase) is particularly poorly documented because the important physical processes take place in the deepest, obscured zones of the molecular envelope. Direct observations of these inner, often small (less than 10 arcsec) zones are essential for building realistic models and need to be done at the best possible spatial resolution and at wavelengths which are not very sensitive to extinction.

In this paper we report the first results of a near-infrared program to study the physical conditions of the inner parts of the molecular envelopes associated with proto-PNe and young, compact PNe. The observations were done in October 1993 with the Canada-France-Hawaii 3.60-meter telescope (CFHT) at Mauna Kea (Hawaii) using a new technique coupling the 256 x 256 pixel NICMOS camera (Redeye) to the Fourier Transform Spectrometer (FTS). The K'–Band was chosen for this program allowing simultaneous spectro-imagery in all the atomic and H_2 lines present in this filter. A detailed description of this instrument called BEAR is given by J.-P. Maillard (this volume). A full description of the data and their analysis will be presented elsewhere.

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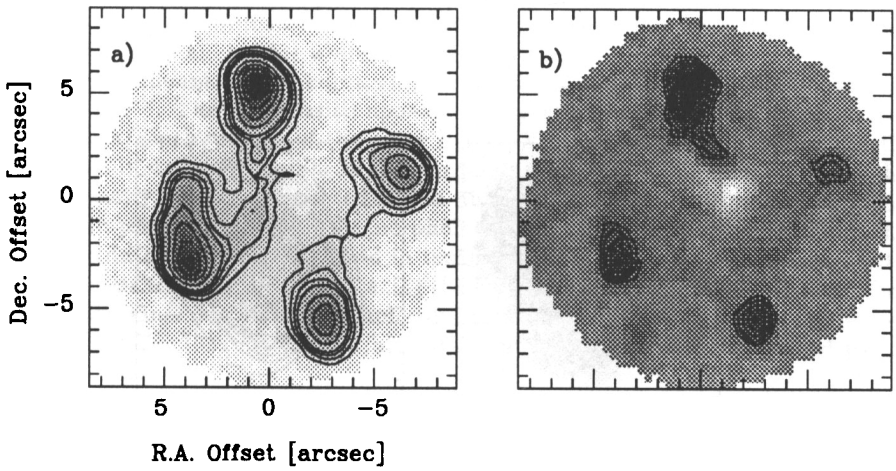

Figure 1. Images of AFGL 2688 in the H_2 1-0 S(1) and 1-0 S(0) transitions (a and b, respectively) after subtraction of the continuum.

2. Results

2.1. The proto-planetary nebula AFGL 2688

AFGL 2688 (the "Egg nebula") is one of the rare sources known to be in the rapidly evolving transition from the AGB to the PN phase. First reported by Ney et al. (1975), AFGL 2688 has been since the subject of numerous observational and theoretical investigations (see Latter et al., 1993 and references therein). It is a bright infrared source with a bipolar optical and near–infrared nebula scattering the light of the cool (F5, $T_{eff} \sim 6500$ K) central star. Using photon scattering models, Yusef-Zadeh et al. (1984) convincingly reproduced the optical and near–infrared appearance of AFGL 2688 (see also Latter et al., 1993) with the equatorial torus lying in the east-west direction and the bipolar axis aligned north-south along the reflection nebula.

Figure 1 displays the BEAR images of the (1-0) S(1) and (1-0) S(0) H_2 transitions (corrected for the continuum) toward AFGL 2688. The H_2 emission shows four bright clumps forming a remarkable cross-like pattern. No trace of continuum or lines from ionized gas is seen in the spectra of these clumps. Weaker H_2 emission clearly links both clumps S and W, and, N and E. The central part of the nebula appears devoid of molecular hydrogen emission and no H_2 emission is detected linking clumps E and W. The continuum emission which is stellar light scattered by the dust of the inner region is mainly detected between clumps N and S. The emission mechanism of the H_2 lines in AFGL 2688 is most likely dominated by shock excitation (Cox et al., in preparation)

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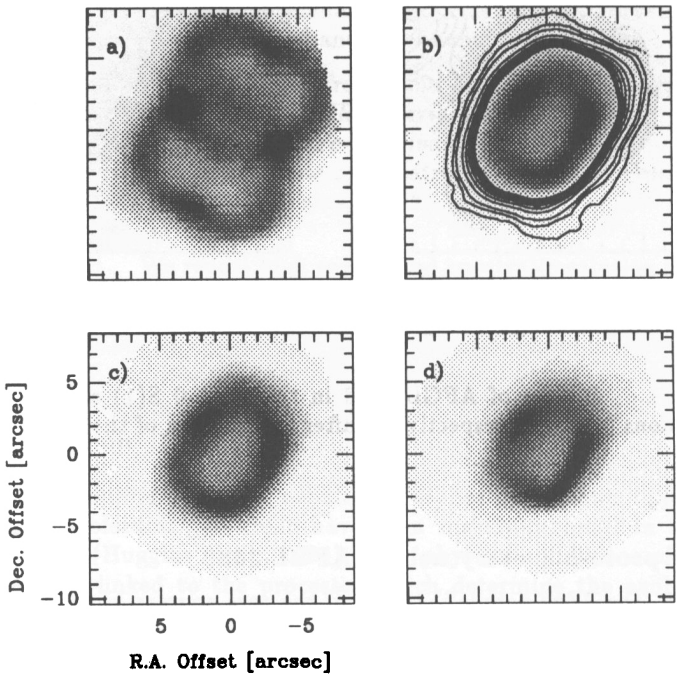

Figure 2. Images of NGC 7027 in the lines of H_2 1-0 S(1), Brγ, HeI (4856 cm^{-1}), and HeII (4567 cm^{-1}) after subtraction of the continuum (from a to d). The contours in the Brγ image display the low level intensities of the ionized cavity (3 to 24 by 3% of the peak value).

2.2. The planetary nebula NGC 7027

NGC 7027 is a key object in the study of PNe because it is a relatively young, strong CO emitter where the inner envelope has been ionized to form a compact HII region whereas the outer region is still relatively intact. The general properties of the neutral envelope have been investigated in detail by many authors e.g., Jaminet et al. (1991). NGC 7027 has also been well studied at arcsec and subarsec resolutions in the near-infrared e.g., Graham et al., (1993).

Images of NGC 7027 obtained with BEAR in the (1-0) S(1) transition of H_2 and in atomic lines of H and He are shown in Figure 2. The molecular hydrogen is distributed along a four leaf clover pattern which surrounds the equatorial torus seen for the first time in its entirety. The inner regions are dominated by the continuum and line emission from the ionized gas including the strong Brγ, and the helium lines. Note that the low level Brγ emission exactly fills in the cavity

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delineated by the outer H_2 loops (Fig. 2). The present data do not confirm the presence of a second inner H_2 structure bounding the ionized gas as found by Graham et al. (1993) which is likely the result of unadequate substraction of the continuum and/or contamination of the nearby He I $4^3S - 3^3P^0$ line at 4733.4 cm^{-1}. The H_2 emission appears strongest at the equatorial torus and at the north/south regions of the outer loops. The overall morphology of the H_2 emission is strikingly similar to the morphology seen in HCO^+ which traces the high-density photon-dominated region abuting the central ionized cavity (Cox et al., in preparation). The H_2 morphology and kinematics (extracted from the present data) can be understood in terms of an inclined expanding torus, with outer loops towards the poles tracing the high-density gas of the PDR which lies along the inner surface of the molecular envelope. The K'-Band line intensities of H_2 in NGC 7027 are compatible with excitation in the UV dominated PDR.

3. H_2 as a diagnostic of the early PN phase

The H_2 morphology and excitation of the two key sources AFGL 2688 and NGC 7027 are consistent with an evolutionary scheme in which: i) AFGL 2688 represents the proto-planetary phase where fast winds ram into the slower expanding AGB envelope, developing strong shocks which are able to excite the H_2 and, ii) NGC 7027 the paradigm of the planetary nebula phase where the ultraviolet radiation of the central, hot degenerated star ionizes the inner cavity and excites the molecular hydrogen in PDRs.

These results demonstrate that high spatial and spectral resolution near-infrared observations of molecular hydrogen are a useful diagnostic to study the evolutionary status of young PNe. Future studies should allow more detailed investigations of the changes in the H_2 morphology and excitation and their links with the rapid evolution from the AGB to the PN phase.

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